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ANALYSIS OF RUNWAY OCCUPANCY TIMES AT MAJOR AIRPORTS.(U)

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ANALYSIS OF RUNWAY OCCUPANCY TIMES AT MAJOR AIRPORTS

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

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16. Abstract

The realization of future airport capacity is greatly dependent on the levels to which interarrival spacings can be reduced. One factor which might appear to limit realization of this potential is the higher runway occupancy times being experienced on some runways in today's environment. Much of the research regarding runway occupancy times has focused on optimal performance capabilities of particular aircraft types. Less attention has been directed towards those other factors which contribute to higher runway occupancy times. This paper identifies specific causes of longer runway occupancy times today as they relate to airline, exit, aircraft, runway, and airport. It goes on to identify what potential, short-term improvement might be expected at particular runways given an appropriately motivated environment.

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Information on previous and current studies of runway occupancy times was provided by the Airport Planning Design Branch (ARD-410), Systems Research and Development Service (SRDS) of the FAA.

There were two persons within MITRE who also made significant contributions. Dr. Ramdas R. Iyer initiated the project and Frank Amodeo provided the support in organizing and reducing the data base.

Peat, Marwick, Mitchell and Company collected the original data for ARD-410, and these observations served as the basic information source for the analysis.

EXECUTIVE SUMMARY

The MITRE Corporation is currently involved in a project to identify and assess potential restrictions to reducing current IFR separation standards on final approach. The lowering of these standards is one factor which can bring about increases in an airport's capacity and reductions in the related aircraft delay. The runway occupancy times being experienced today at some airports pose one potential restriction which might inhibit further reductions to those standards. This analysis, conducted by MITRE Metrek, investigated the factors that contribute to currently observed runway occupancy times as they relate to airline, exit, aircraft, runway, and airport.

The analysis utilized the observations collected in 1972 and 1973 by Peat, Marwick, Mitchell and Company (PMM&Co.) for the Airport Planning Design Branch (ARD-410) of the FAA. This data was sorted by airport and runway and ordered by exit, carrier, and runway occupancy time. The data was then analyzed to assess the various motivational patterns of individual carriers and groups of carriers. As a part of this process, average runway occupancy times were calculated for runways, individual carriers on runways, groups of carriers on runways, and exits. A summary of these results is provided in Table A on the following page.

The analysis concluded that many factors contribute to runway occupancy times. Some of these were: minimum time to gate, least number of turns to gate, company procedures, incoming traffic density, flight crew performance and preference, and passenger comfort and confidence. The most dominant motivating factor in determining a carrier's exiting pattern appeared to be the desire to get off at the exit most conveniently located to the terminal gate.

Reducing runway occupancy time was not usually a direct motivating factor, but operational factors contributed to motivate a carrier to exit quickly and thereby produced consistently low runway occupancy times. Significant differences in runway occupancy times were found between those carriers who were motivated by operational factors to exit early and other carriers. In some cases the difference in runway occupancy time between the two groups was as high as eight seconds. The performance of the motivated carriers indicated that potential for consistently lower runway occupancy time exists within the current runway/exit system.

The analysis went on to investigate whether even greater potential exists for improvements in runway occupancy times than that displayed by the motivated carriers. It concluded that at most airports good, feasible exits exist that were currently underutilized. If motiva-

TABLE A

SUMMARY OF RUNWAY OCCUPANCY TIMES

Aircraft Group	Runway	Average Runway Occupancy Time		Motivated Carrier* Runway Occupancy Time (Seconds)	Potential Runway Occupancy Time (Seconds)
		Per Data Base Analysis (Seconds)	FAA/Airport Task Forces (Seconds)		
Group 3 (BAC 111, DC-9, 737, 727)	ATL 27R(26)	51.4	50	49.5	42
	BUF 5	50.7	***	47.1	38
	BUF 23	55.9	***	52.3	38
	DEN 26R	51.5	52	48.4	41
	LAX 25L	48.2	43	44.9	37
	LAX 25R	52.6	45	50.5	38
	LGA 22	43.3	52	**	41
	LGA 31	40.7	51	**	36
	SFO 28R	47.4	50	46.3	46
	SFO 28L	49.3	47	49.1	46
Group 4 (707, DC-8, L1011, 747)	DEN 26R	55.1	60	**	41
	LAX 25L	50.9	49	49.6	37
	LAX 25R	60.2	52	57.3	38
	SFO 28R	57.5	52	56.0	46
	SFO 28L	55.0	52	53.4	47

*Those carriers motivated by operational factors to exit early
**No differences in motivational patterns surfaced
***No FAA/Airport Task Force Study

tions were changed to reflect a need to minimize runway occupancy time by use of the first feasible exits, further potential reductions of 2-14 seconds could be anticipated.

The analysis revealed that the average runway occupancy times computed from the data base did not always coincide with the numbers used by the FAA/Airport Task Forces in their individual airport analyses. The theoretical time-distance braking curves used to develop current runway occupancy time potential were reasonable and generally coincided with the principles of the FAA's Systems Research and Development Service's recent studies of high speed exits.

Improvements in runway occupancy times beyond those estimated based on current runway potential can be realized only through design and implementation of systematic, well lighted, and clearly designated high speed exits on runways with good braking surfaces.

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1. INTRODUCTION

1.1 Background

As construction costs continue to escalate and airports become constrained with respect to expansion, it becomes increasingly important that the potential capacity of existing runway facilities be realized. One factor affecting an airport's potential capacity and related aircraft delay is the spacing between arriving aircraft on final approach. The MITRE Corporation is currently involved in a project to identify and assess potential restrictions to reducing current IFR separation standards.[1] The runway occupancy times (ROT's) being experienced in today's airport environment pose one potential restriction which might inhibit further reductions to those standards.

Data regarding runway occupancy times and related analyses are relatively scarce. Almost all work to date has focused on relationships of optimal performance characteristics of specific aircraft types and/or the placement and design of individual exits. This emphasis tends to disregard the operational need for consistent, sufficiently low runway occupancy times.

1.2 Scope/Purpose

Exiting at optimal locations or stopping in the minimum amount of time becomes meaningless if for one reason or another a pilot has no incentive to approximate these performance standards. While few question the fact there exists a disparity between optimal and presently observed runway occupancy times, little attention has been directed towards reasons for these differences as they relate to airline, exit, aircraft, runway, and airport. It is important that individual components of runway occupancy times are understood and analytically described so that appropriate measures for achieving the lower times and reduced standards can be implemented in that field.

With this in mind, the purpose of this analysis is to identify the current air carrier motivational patterns that contribute to higher runway occupancy times and thereby add to delays and reduce airport capacity. In order to identify these patterns, the analysis relies heavily on the information in a data base assembled by Peat, Marwick, Mitchell and Company (PMM&Co.). These observations contain data regarding exit locations and runway occupancy times which form the nucleus of the analysis. After having determined the reasons for certain motivational patterns, the analysis goes on to estimate what potential exists for improvement in runway occupancy times if these patterns were altered.

2. DATA EVALUATION

2.1 Information Sources

The most complete and readily available data base on runway occupancy times was collected by Peat, Marwick, Mitchell, and Company (PMM&Co.) in 1972 and 1973. The observations were made at selected airports for arrivals primarily during VFR conditions. Factors such as traffic density, runway conditions, and braking technique were generally not recorded. Additional problems were encountered because of alterations to runway configurations and designations since the time of data collection. While the data base did have limitations, it provided the most complete and available information source of runway occupancy times.

The second major source of information came from the Airport Taxi Charts found in the Department of Commerce's "Instrument Approach Charts." These diagrams depict runway layouts along with the accompanying exits and taxiways. The exit numbering system utilized by PMM&Co. was transfered to these diagrams so that the data base could be more easily understood. These diagrams are found in Appendix A.

The final major information source came from an airline publication[2] compiled for travel agent use. It presents the gate locations of the individual carriers at the selected airports. The information on these diagrams was also transferred to the Airport Taxi Charts (Appendix A) so that the proximity of carriers' gates to runway and exits could be determined.

By consolidating the information contained in these referenced documents, a more complete overview of airport operations was achieved. In some cases the information was modified to accomodate runway modifications that have taken place since the time of the data collection. For example, the runway currently designated as ATL 26 was previously ATL 27R. In all data presentations the original designation was used with parenthetical disclosure of the current identifier.

2.2 Data Base Reduction

In order to extract a pertinent set of records from the PMM&Co. data base, it was necessary to refine and reduce the original data base. Some procedures took the form of ordering the observations while others reflected elimination of data for one reason or another.

The initial data sort placed all records for an individual runway in a separate file. Secondly, because the initial data collection procedure included both arrivals and departures, all departures were excluded. The next step was to eliminate all records whose runway occupancy time was less than zero or greater than 100. This was done because those negative times were not theoretically possible and the higher times were felt to be irregularities of one type or another. A further review of the data led to the conclusion that times of less than ten seconds were also technically impossible and they were eliminated. It must be pointed out that there were very few occupancy times in this range and this assumption was highly conservative and had little significance on the analysis.

Files were then sorted into groups of aircraft (1 thru 4, with 5 being unidentified aircraft types). Groups 1 and 2 were primarily small, general aviation aircraft which have a gross takeoff weight of less than a DC-9. Two and three engine jets comprised most of Group 3 while Group 4 was made up of four engine jets and all heavy aircraft. This analysis concerned itself primarily with the Group 3 and 4 aircraft which were the overwhelming majority of the commercial airline fleet and represented the greatest percentage of operations at the airports selected for analysis. The very nature of Group 5 aircraft (unidentified aircraft types) precluded these observations from further consideration.

Each file (runway) was examined to determine the remaining number of observations. Only those files containing more than 75 records were considered to contain enough data to be representative of motivational/exiting patterns. All serious data errors were eliminated and less serious data errors were corrected where possible. Because individual carriers were scrutinized only those carriers with three or more observations were analyzed. General aviation aircraft classified as Group 3 were also eliminated due to the fact that their terminal facilities and related exits were often in different locations on the airport from the main passenger terminal(s).

2.3 Data Base Quality

A large number of records in the PMM&Co. data base were unusable for this analysis either because of data omissions or errors. Runway occupancy times of less than ten and greater than one hundred seconds were eliminated prior to the initial runway sort. Accordingly, only an estimate was calculated for each airport to indicate the order of magnitude of the number of records eliminated in this first phase of the data reduction. The percentages of records considered unusable for this reason were:

- Atlanta 15%
- Buffalo 6%
- Denver 15%
- La Guardia 4%
- Los Angeles 8%
- San Francisco 8%

The following were representative of other types of unusable data:

- Group 1 and 2 aircraft
- unidentifiable aircraft types
- blank aircraft types
- blank exits
- incorrect runways or exits
- other errors

The rates for these groups of unusable data varied by runway from approximately fifteen to fify-nine percent. These percentages were slightly understated because some observations contained highly suspicious data which was not eliminated as unusable because the data could not be proved incorrect. Table 2-1 presents a reconciliation of the observations in the PMM&Co. data base after sorting by runway and the final data base used in this analysis. What was originally thought to be a relatively large data base has proved to be somewhat limited and thereby restricted the analysis to a relatively narrow scope.

2.4 Runway Data

A review of the initial aircraft groupings revealed that some slight modifications were needed so that aircraft with similar performance characteristics were placed in the same classification. In some cases this was caused by the inability of the data collectors to identify particular aircraft types and to differentiate between aircraft models. The most important of these revisions was to transfer all B-707's into Group 4 from Group 3 thereby placing all four engine jets into a group with

TABLE 2-1

RECONCILIATION OF INITIAL PMM&CO. AND REDUCED DATA BASES

Runway	Initial Sort by Runway of PMM&Co. Data Base*	Elimination of Aircraft Groups 1 & 2	Elimination of Aircraft Groups 5	Data Errors	Incomplete or Unusable Data	Remaining Records	Percent Reduction**	Remaining Records Class 3	Remaining Records Class 4
ATL 27R(26)	127	11	3	3	2	108	15	97	11***
BUF 5	92	51	3	0	0	38	59	33	5***
BUF 23	263	124	5	0	0	134	49	124	10***
DEN 26R	527	85	6	4	18	414	21	314	100
LAX 25L	307	19	13	6	21	248	19	98	150
LAX 25R	251	2	1	49	11	188	25	138	50
LGA 22	430	54	7	31	14	324	25	315	9***
LGA 31	140	24	2	0	10	104	26	103	1***
SFO 28R	213	39	5	4	11	154	28	93	61
SFO 28L	363	28	24	14	29	268	26	138	130

*ROT's of less than ten and greater than one hundred seconds are eliminated prior to initial runway sort

**Percent reduction from initial sort by runway to remaining records

***Not considered for further analysis because of limited number of observations

the wide-bodied aircraft. The revised system is consistent with the classification scheme in FAA Handbook 7110.65A "Air Traffic Control," Paragraph 1121 - Intersecting Runway Separation, which prescribes groupings based on an aircraft's ability to brake and hold short of an intersecting runway. The primary aircraft types included in the final groups were:

Group 3 - BAC 111, DC-9, B-737, B-727
Group 4 - B-707, DC-8, L1011, DC-10, B-747

For analysis and data presentation purposes, Groups 3 and 4 were segregated. Data for each runway and aircraft group were broken down both by carrier and by exit. These data presentations are located in Appendix B.

The mean runway occupancy times ranged from approximately 40-60 seconds. The majority of times fell within the 47-57 second range. Mean ROT's for the Group 4 aircraft were generally higher than the Group 3 aircraft on the same runway. However, it was difficult to make direct comparisons with these numbers due to the varying mix of observations among carriers. In some instances the average time for Group 4 aircraft for an individual carrier was equal to, or even lower than, the same carrier's average ROT for Group 3 aircraft.

The standard deviations for overall runway occupancy times ranged from approximately eight to sixteen seconds. The majority of these were in the eight to ten second range. These figures were higher than had been anticipated and were probably attributable to the wide variation in exiting patterns of the carriers. For individual carriers and exits, the standard deviations of the mean runway occupancy times tended to be significantly lower.

The consolidated version of the pertinent, overall data found in Appendix B is displayed in Table 2-2. Detailed discussions and interpretations are presented in the following sections.

TABLE 2-2

OVERALL RUNWAY OCCUPANCY TIME MEANS AND STANDARD DEVIATIONS

	Runway	Mean ROT (Seconds)	Standard Deviation (Seconds)	Number of Records
Group 3 (BAC 111, DC-9, 737, 727)	ATL 27R (26)	51.4	7.5	97
	BUF 5	50.7	13.8	33
	BUF 23	55.9	8.7	124
	DEN 26R	51.5	8.4	314
	LAX 25L	48.2	10.4	98
	LAX 25R	52.6	14.1	138
	LGA 22	43.3	9.5	315
	LGA 31	40.7	8.5	103
	SFO 28R	47.4	9.2	93
	SFO 28L	49.3	8.1	138
Group 4 (707, DC-8, L1011, DC-10, 747)	DEN 26R	55.1	9.4	100
	LAX 25L	50.9	9.6	150
	LAX 25R	60.2	16.8	50
	SFO 28R	57.5	16.5	61
	SFO 28L	55.0	13.4	130

3. MOTIVATIONAL PATTERNS

3.1 Influencing Factors

Numerous hypotheses have been offered regarding the factors that influence runway occupancy times. In certain isolated cases these are somewhat absolute and relatively easy to track down. An example of this would be a company procedure which establishes optimal speeds or exits at which a pilot should exit. Similarly, a company goal to minimize the time it takes to reach the carrier's gate might be a motivating factor either for scheduling purposes or cost considerations. However, other factors appear to be more vague. Maximizing passenger comfort and confidence falls within this category. A pilot's knowledge of an individual runway and his desire to make as few turns as possible are also hard to isolate. The density of incoming traffic might also be one factor which alters or determines motivational patterns. Needless to say, the layout and design of the runways and exits cannot be overlooked.

All of the above considerations, either physical, emotional, or operational are reflected in patterns of exit use. These patterns in turn directly relate to an individual carrier's overall runway occupancy time. However, no one has suggested that the reduction of runway occupancy time in itself is a motivating factor. Only those factors which otherwise motivate a carrier to exit early can produce consistently low (not necessarily minimum) runway occupancy times. Our analysis indicated that the most dominant motivating factor in determining a carrier's exiting pattern was the desire to get off at the exit most conveniently located to the terminal gate. This point became evident when reviewing the runway data presentations.

3.2 Individual and Common Exiting Patterns

Three types of exiting patterns were evident in the analysis, individual, common, and none at all. In all cases the exiting pattern appeared to be determined by the relationship of the terminal (and carrier's location within the terminal) to the runway and related exits. Each carrier had his own individual exiting pattern because of unique terminal gate locations. If the carrier had enough traffic at a particular airport, it may warrant occupation of a complete terminal or satellite facility. In most cases a carrier was not this dominant or large and could justify only partial use of a facility. This brought about common motivation and common exiting patterns. In particularly large facilities, common motivational patterns encompassed groups of terminals, as opposed to groups of carriers. In a relatively

few cases, no motivational patterns were evident. This was a unique occurrence which was caused by facility design which rewarded or penalized carriers equally for using the same exit.

3.3 Motivated Carriers

An ordering process was established to determine levels of motivation. This process assumed that the carrier whose terminal gate location was closest to the runway threshold was the most highly motivated to exit early, and vice versa. The application of this concept would have been relatively simple if all terminals ran parallel to runways and conveniently placed exits provided access to each. However, as previously discussed, the design of facilities often induced common motivational factors which were displayed in similar exiting patterns. Therefore, motivated carriers were defined as the singular carrier or carrier group that had the greatest motivational impetus to exit quickly. The remaining carrier or carrier groups were designated as other carriers. An example of this concept can be found by looking at the layout for BUF 23 found in Appendix A-3. American and United were motivated carriers while Eastern and Allegheny were other carriers.

At almost all airports there were significant differences in the mean runway occupancy times for the motivated carriers and other carriers. These differences are shown in Table 3-1. The lower runway occupancy times reflected the utilization of exits closer to the runway thresholds.

TABLE 3-1

MEAN RUNWAY OCCUPANCY TIME OF MOTIVATED AND OTHER CARRIERS

	Runway	Motivated Carriers* (Seconds)	Other Carriers (Seconds)	Δ ROT (Seconds)
Group 3 (BAC 111, DC-9, 737, 727)	ATL 27R (26)	49.5	52.8	3.3
	BUF 5	47.1	55.5	8.4
	BUF 23	52.3	57.6	5.3
	DEN 26R	48.4	53.6	5.2
	LAX 25L	44.9	51.3	6.4
	LAX 25R	50.5	57.4	6.9
	LGA 22	43.3	**	**
	LGA 31	40.7	**	**
	SFO 28R	46.3	49.7	3.4
	SFO 28L	49.1	49.7	.6
Group 4 (707, DC-8, L1011, DC-10, 747)	DEN 26R	55.1	**	**
	LAX 25L	49.6	51.3	1.7
	LAX 25R	57.3	62.5	5.2
	SFO 28R	56.0	59.6	3.6
	SFO 28L	53.4	59.0	5.6

*Those carriers motivated by operational factors to exit early

**No differences in motivational patterns surfaced

4. RUNWAY OCCUPANCY TIME POTENTIAL

In order to determine the ROT potential for the various runways, it was necessary to review the theoretical time-distance braking relationships of commercial aircraft. After comparing observed carrier performance to these curves, estimations of potential ROT performance were made.

4.1 Theoretical Time-Distance Braking Curves

Landing procedures of transport aircraft are made up of three separate phases: a) the flare maneuver, b) the point of the main gear touchdown to the point where the nose-wheel touches down, and c) the ground braking distance and roll. Runway occupancy time consists of the time it takes to execute these three maneuvers. The first two phases take between 7-11 seconds and remain approximately unchanged for different types of airplanes within the present fleet of commercial aircraft. The last phase depends on the aircraft braking capability and on the pilot's technique and preference as well as the location of exits on the runway. The time related to slowing down and making a safe exit is between 15-35 seconds. Therefore, total runway occupancy time theoretically should lie somewhere between 22-46 seconds.

Landing distance is a function of the aerodynamic characteristics, landing weight and approach speed as well as airport altitude, runway slope and wind. The Federal Aviation Regulation (FAR) landing distances for different types of transport category aircraft lie between 3500 and 6500 feet. The FAR landing distance must be divided by 1.667 to get the actual landing distance of the aircraft. FAR landing distances for individual aircraft types are shown in Appendix C.

Figure 4-1 shows the theoretical time-distance history from the threshold for a typical commercial aircraft. The first phase of the landing is a linear segment which depicts the time and distance it takes to execute the flare maneuver at an assumed speed of 111 knots from a height of 50 feet over threshold to touchdown. The second phase is a short curvilinear segment representing the point of the main gear touchdown to the point where the nose-wheel touches down. During this transition from a landing to braking configuration a slight reduction in speed takes place. The third phase, or ground run, depends not only on the aircraft characteristics (spoilers, thrust reversers, and wheel braking capability), but on the pilot and on his knowledge of the runway on which he is landing. Deceleration rates of 10.5 and 5.5 feet per second/second are reflected in the full and moderate braking curves respectively. Accordingly, it takes

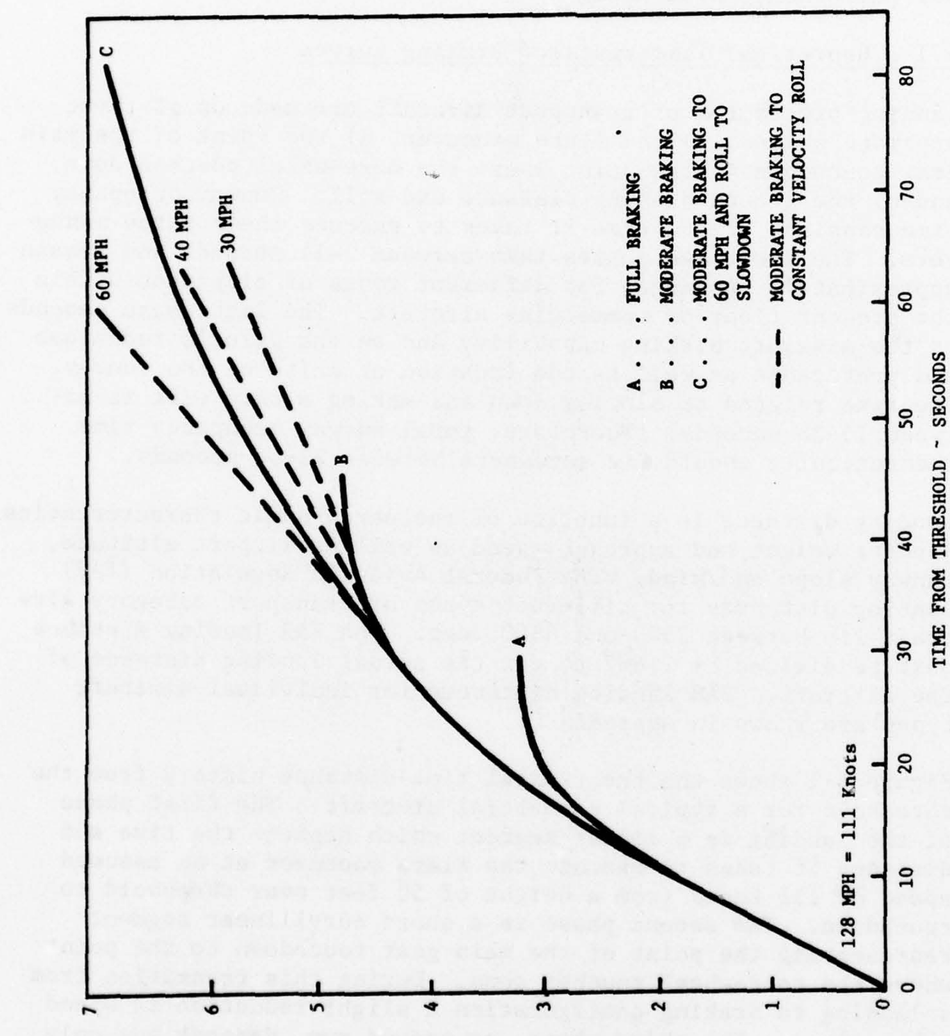

FIGURE 4-1
THEORETICAL TIME-DISTANCE BRAKING CURVES
FOR AIR CARRIER AIRCRAFT

30 seconds and 3200 feet for the aircraft to come to a stop with full braking and 45 seconds and 4500 feet to come to a stop with moderate braking. If the pilot knows that a particular runway has an exit (which he wants to take) beyond 5,000 feet and he has the capability of stopping the aircraft in 3,200 feet (Curve A in Figure 4-1) with full braking, he may choose to apply moderate braking (Curve B in Figure 4-1) and take the exit that he prefers. It there is an exit just beyond 3,200 feet, say at 3,400 feet and if the pilot prefers to take this exit, then he will choose to utilize full braking capability of the aircraft (in this case the runway occupancy time will be smaller). For identical types of exits (high speed, right angled, angled) the distance from the threshold is a very important criteria in reducing runway occupancy time (e.g., a right angled exit at 3,250 feet will give 29 seconds as runway occupancy time and any other right angled exit beyond 3,250 feet will result in larger runway occupancy time). Correspondingly, a 60 m.p.h. exit at 4,200 feet can also yield an occupancy time of 29 seconds with appropriate braking.

4.2 Performance at Predominant Exits

While the various time-distance braking curves are all theoretically possible, they do not serve any useful purpose unless they can be related to current operational performance The first step in analyzing this relationship was to select a group of observations which reflect carriers' performance on each runway This was accomplished by determining the predominant exit on each runway and calculating the mean runway occupancy time for all observations at that exit. The distance from threshold was then calculated for each exit. Only the predominant exit was used rather than all exits to reduce the superfluous data which might be caused by irregularities. These times and distances are presented in Table 4-1 and are also plotted on the time-distance braking curves in Figure 4-2.

The conclusion derived from this procedure was that carrier performance approximated Curve C (Moderate Braking and Roll) of Figure 4-2. While certain performance factors were assumed in formulating the curve, this does not mean that this performance technique was employed by the pilots in the data observations. They could have landed long and applied more strenuous braking techniques or rolled faster and then utilized harder braking as they approached the exit. The lack of information in the data base limits further investigation in this area. This was not totally important as long as carriers could and did perform along the curve. The question then became one of determining how far down the curve they can go and still be assured of safe and realistic exiting patterns.

TABLE 4-1

MEAN RUNWAY OCCUPANCY TIMES AT PREDOMINANT EXIT

	Runway	Exit ROT (Seconds)	Exit Distance (Feet)	Sample Size	% of Traffic At Exit
Group 3 (BAC 111, DC-9, 737, 727)	ATL 27R(26)	52.3	6694	57	59%
	BUF 5	44.8	4665	19	58
	BUF 23	57.3	6203	89	72
	DEN 26R	48.4	5967	162	52
	LAX 25L	49.2	6000	40	41
	LAX 25R	49.4	5515	76	55
	LGA 22	40.4	4955	186	59
	LGA 31	42.2	5058	53	51
	SFO 28R	47.3	5664	67	72
	SFO 28L	48.3	5802	130	94
Group 4 (707, DC-8, L1101, DC-10, 747)	DEN 26R	60.2	6457	50	50
	LAX 25L	50.1	6536	78	52
	LAX 25R	56.6	5515	14	28
	SFO 28R	48.0	5664	37	61
	SFO 28L	48.4	5802	87	67

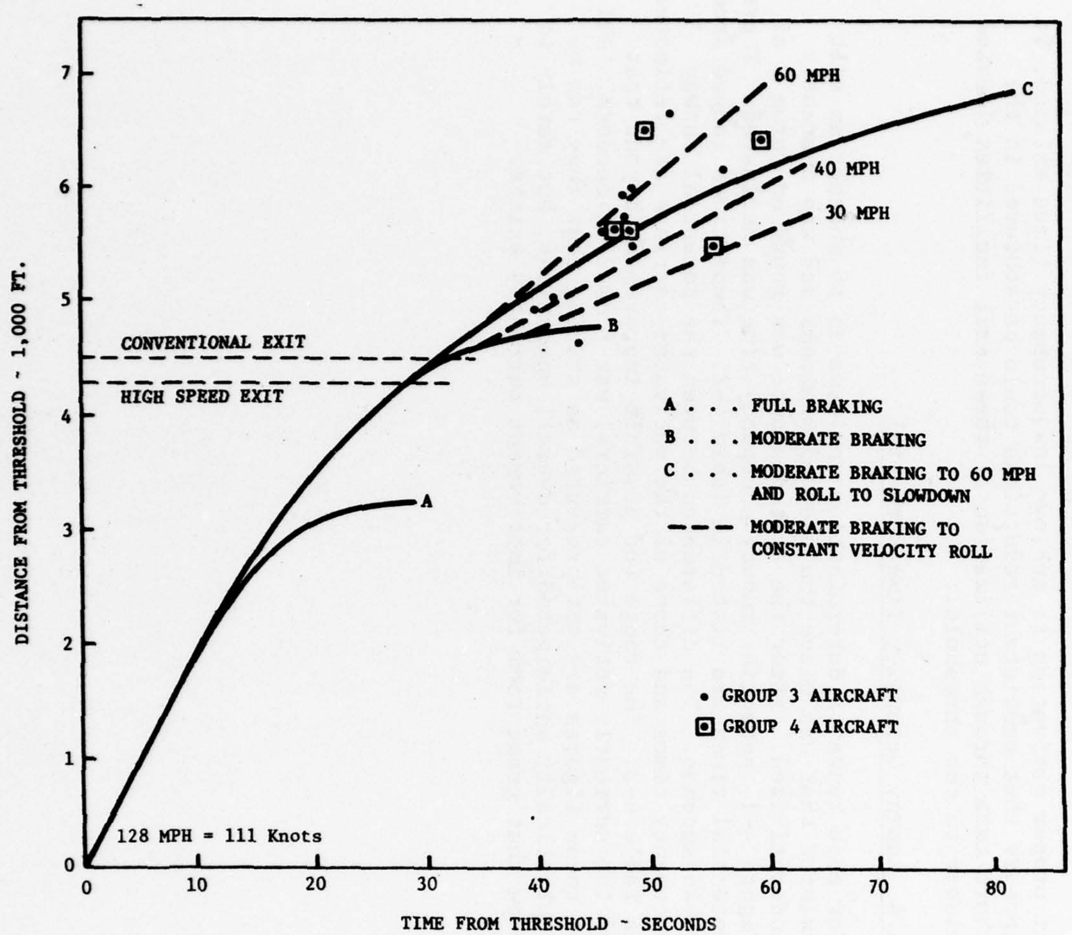

FIGURE 4-2
RELATIONSHIP OF MEAN RUNWAY OCCUPANCY TIMES AT PREDOMINANT EXITS TO TIME-DISTANCE BRAKING CURVES

4.3 Potential Use of Existing Exits

The data base contained a substantial number of observations (other than those shown in the previous figure) at high speed exits at 4300 feet and conventional exits at 4500 feet. At most airports good feasible exits were located between the observed lower bound (4300/4500 feet) and the exits taken by the motivated carriers.

If proper motivation to achieve low occupancy times existed, it appears that consistent reductions could be achieved in the short term through utilization of these exit facilities located closer to the threshold.

4.4 Runway Occupancy Time Potential

For each runway a determination was made as to whether an exit existed that was above the assumed minimums and was currently underutilized. After the exit distance was found on Curve C of Figure 4-1, potential runway occupancy time was estimated These potential times are listed in Table 4-2. These times ranged from 38-46 seconds. The differences between the potential runway occupancy times and those of the motivated carriers are reflected in Table 4-3. The range (of possible improvement beyond that of the currently motivated carriers) was from 2-14 seconds. All of these figures are not presented as stating that they can be realistically anticipated for overall operations, but merely to show that great room for improvement currently exists.

TABLE 4-2

LOCATION AND RUNWAY OCCUPANCY TIMES OF MORE EFFICIENT EXITS

	Runway	Exit Distance (Feet)	Potential ROT (Seconds)
Group 3 (BAC 111, DC-9, 737, 727)	ATL 27R (26)	5124	42
	BUF 5	4665	38
	BUF 23	4768	38
	DEN 26R	5087	41
	LAX 25L	4607	37
	LAX 25R	4666	38
	LGA 22	4955	41
	LGA 31	4291	36
	SFO 28R	5664	46
	SFO 28L	5802	46
Group 4 (707, DC-8, L1011, DC-10 747)	DEN 26R	5087	41
	LAX 25L	4607	37
	LAX 25R	4666	38
	SFO 28R	5664	46
	SFO 28L	5802	47

TABLE 4-3

RUNWAY OCCUPANCY TIMES OF MOTIVATED CARRIERS AND EFFICIENT EXITS

	Runway	Motivated Carrier* ROT (Seconds)	Potential ROT At Efficient Exit (Seconds)	Δ ROT (Seconds)
Group 3 (BAC 111, DC-9, 737, 727)	ATL 27R (26)	49.5	42	7.5
	BUF 5	47.1	38	9.1
	BUF 23	52.3	38	14.3
	DEN 26R	48.4	41	7.4
	LAX 25L	44.9	37	7.9
	LAX 25R	50.5	38	12.5
	LGA 22	43.3	41	2.3
	LGA 31	40.7	36	4.7
	SFO 28R	46.3	46	.3
	SFO 28L	49.1	46	3.1
Group 4 (707, DC-8, L1011, DC-10, 747)	DEN 26R	55.1	41	14.1
	LAX 25L	49.6	37	12.6
	LAX 25R	57.3	38	9.3
	SFO 28R	56.0	46	10.0
	SFO 28L	53.4	47	6.4

*Those carriers motivated by operational factors to exit early

5. OBSERVATIONS/CONCLUSIONS

5.1 Data Base Limitations

The entire analysis was based on the records taken from the PMM&Co. data base. In several cases the information contained in observations of particular airport runways was highly questionable. However, the fact remains that the information therein represented the best numbers available for this particular analysis. Although the confidence level precluded any categorical conclusions being drawn from this analysis, the results provided significant insight into the various motivational factors which affected runway occupancy times.

5.2 Motivational Patterns

The single most significant contributing factor to higher runway occupancy time was made by carriers utilizing exits which were convenient to terminal gate locations. This fact was made clear by the exiting patterns of most carriers at almost all airports. An examination of the runway occupancy times showed that as expected carriers that exited early almost always had lower runway occupancy times than carriers that exited farther from the runway threshold. The difference in average occupancy between carriers that were operationally motivated to exit early and those of the other carriers was usually significant, ranging from 2-8 seconds. Only a few cases of runways which rewarded or penalized all carriers' runway occupancy times equally were found (e.g., La Guardia). In some cases the actual exit location and runway configuration contributed to higher runway occupancy times (e.g., San Francisco). Finally, overall runway occupancy time standard deviations were three to four seconds higher than anticipated. While the standard deviations of ROT's for individual carriers and exits were significantly lower than for the overall runway, there did not appear to be any material differences between the standard deviations of carriers with different motivational patterns.

5.3 Potential for Reducing Runway Occupancy Time

Individual and overall runway occupancy times in the forty to forty-five second range were found on selected runways. This affirmed the theory that overall ROT's in this range were not only possible but were actually taking place. Accordingly, given the exits that currently exist and the proper motivation, it appears that there is significant potential for reductions of overall runway occupancy in the short term. These potential reductions could approximate two to fourteen seconds below the

runway occupancy times currently achieved by motivated carriers at individual airports.

5.4 Consistency of Theories and Conclusions

Many groups or individuals have presented theories regarding runway occupancy times. While this analysis has not attempted to set standards or minimums, it is useful for credibility purposes to determine whether the theories and conclusions are in harmony with other analyses.

Because no information regarding braking technique was recorded during the observations, it was necessary to determine whether the theoretical distance-braking curves appeared to be reasonable representations of runway occupancy times under VFR conditions. The observations at the dominant exits of the selected airports for both Group 3 and Group 4 aircraft approximated the moderate braking and roll curve. This was the most conservative of the three curves and appeared to be a reasonable limitation for the analysis. Because of the similarity of performance of all aircraft types displayed in the data base, this methodology was chosen over a system which would establish various exit distances and ROT's for a wide range of commercial jet aircraft. The analysis did not estimate runway occupancy times below the 4200/4500 feet level because there were very few observations in the data base to substantiate performance at those levels. In general, the potential ROT's developed in the analysis approximated the goals developed by Systems Research and Development Service in their runway occupancy time evaluation.[3] They were:

	Minimum Ideal ROT	ROT Goal
Group 3	26 sec.	42 sec.
Group 4	28 sec.	45 sec.

The most significant difference uncovered in the analysis was related to the average runway occupancy times at selected airports and the standards used by the FAA/Airport Forces for capacity calculations. These differences are presented in Table 5-1.

These differences were supposedly caused by relying on "ad hoc" estimations by individuals or the output of generalized models which could not compensate for constraints and idyosyncrasies of individual runways. This became particularly important when considering the exiting patterns displayed by individual carriers.

TABLE 5-1

COMPARISON OF DATA BASE AND TASK FORCE ROT'S

Aircraft Group	Runway	Average Runway Occupancy Time: Per Data Base Analysis (Seconds)	Average Runway Occupancy Time: FAA/Airport Task Forces (Seconds)	ΔTask Force ROT (Seconds)
Group 3 (BAC 111, DC-9, 737, 727)	ATL 27R(26)	51.4	50	-1.4
	BUF 5	50.7	*	-
	BUF 23	55.9	*	-
	DEN 26R	51.5	52	+0.5
	LAX 25L	48.2	43	-5.2
	LAX 25R	52.6	45	-7.6
	LGA 22	43.3	52	+8.7
	LGA 31	40.7	51	+10.3
	SFO 28R	47.4	50	+2.6
	SFO 28L	49.3	47	-2.3
Group 4 (707, DC-8, L1011, 747)	DEN 26R	55.1	60	+4.9
	LAX 25L	50.9	49	-1.9
	LAX 25R	60.2	52	-8.2
	SFO 28R	57.5	52	-5.5
	SFO 28L	55.0	52	-3.0

*No FAA/Airport Task Force Study

5.5 Future Data Collections

This analysis was primarily limited by the lack of information regarding braking technique and secondarily by the scope and nature of the data base. A larger and more complete data base would have enabled the analysis to extend into related areas which would have provided additional insight into runway occupancy times. As runway occupancy times on dry runways become a more limiting factor of the ATC system, greater demands will be made for increased understanding and upgraded data bases. Further data collection, especially in IFR conditions, would greatly enhance understanding of runway occupancy times. Data of this nature would enable comparisons of IMC to VMC performance and facilitate better current and future capacity estimates.

APPENDIX A

AIRPORT TAXI CHARTS

The airport taxi charts contained in this appendix have information for the PMM&Co. exit numbering system and airline terminal locations superimposed on them. They are:

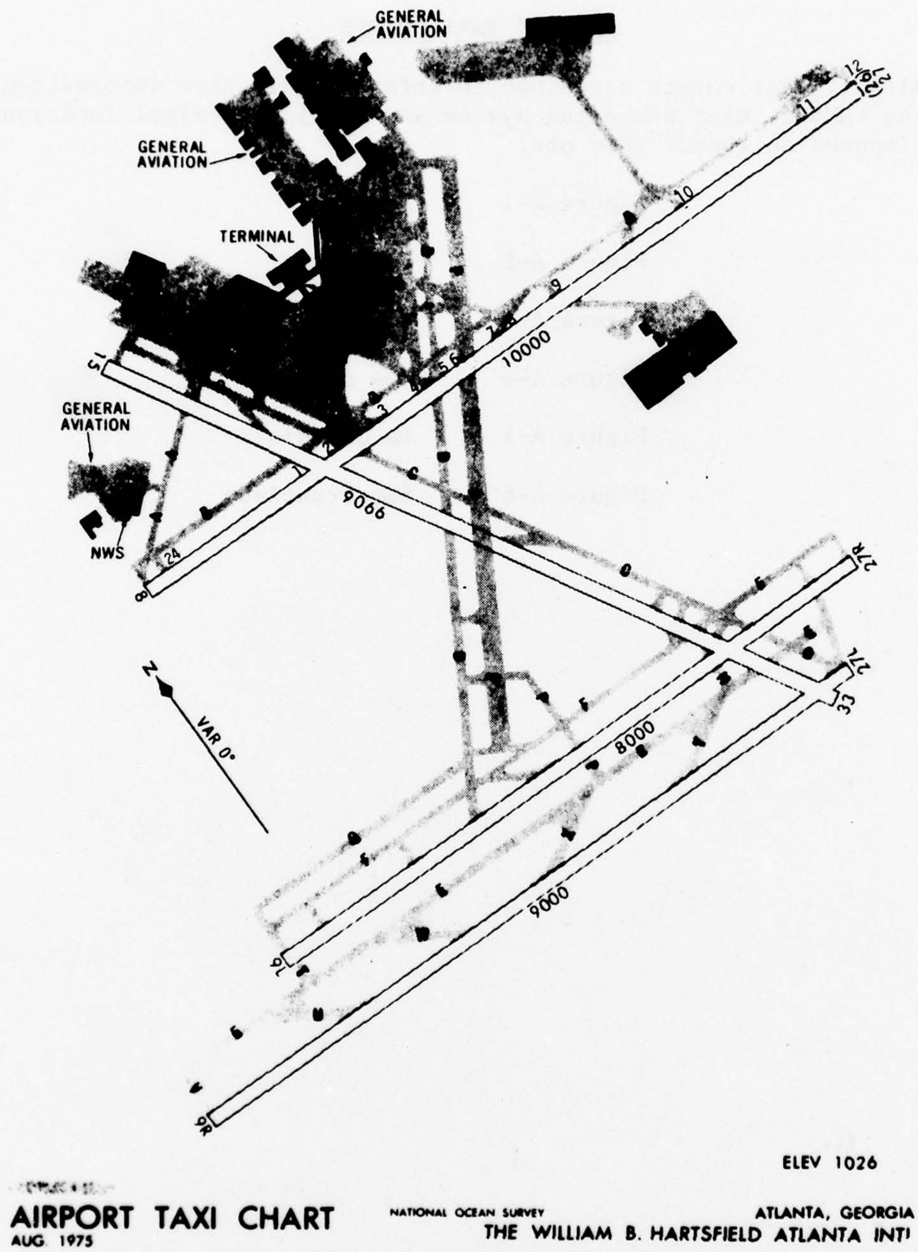

FIGURE A-1
ATLANTA AIRPORT TAXI CHART

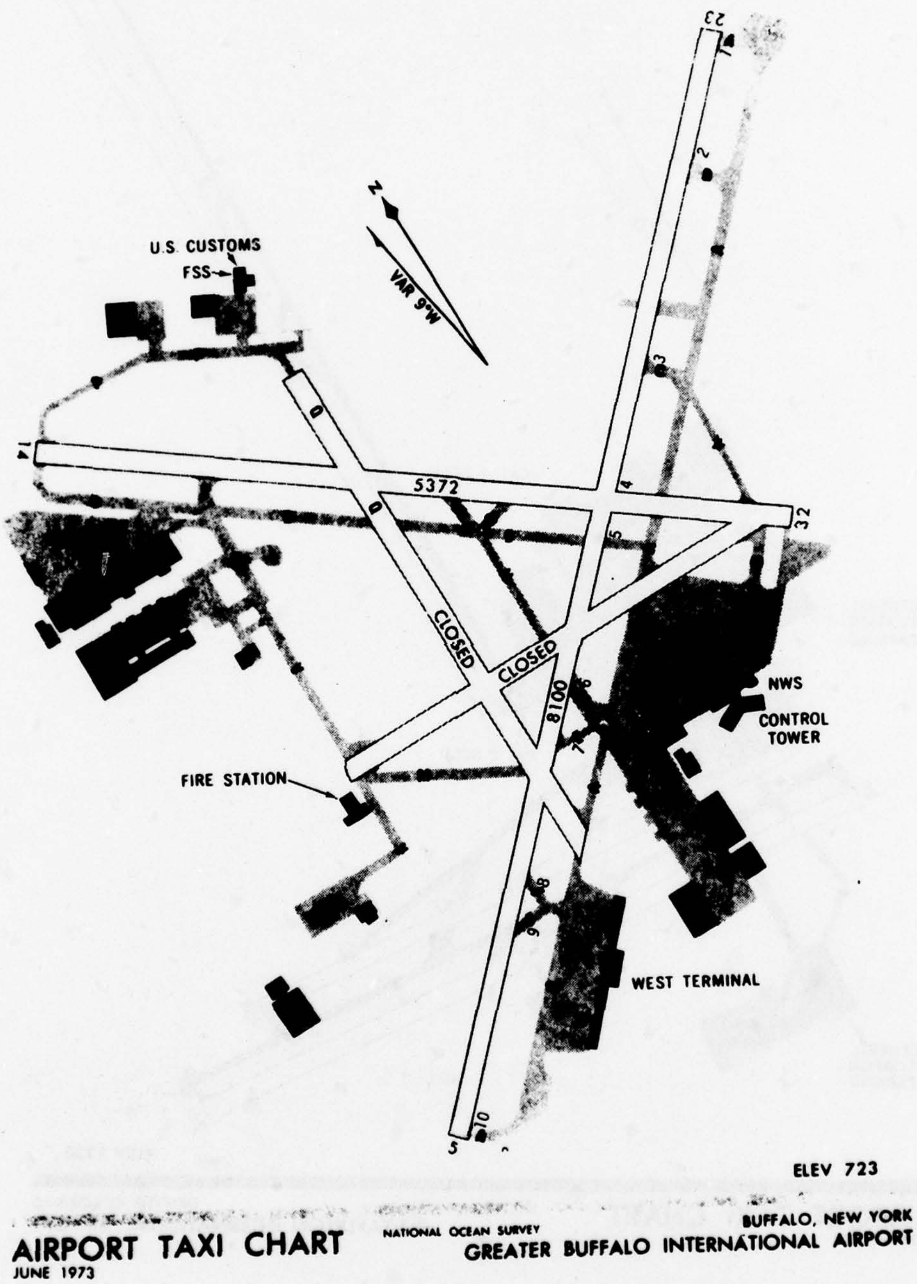

FIGURE A-2
BUFFALO AIRPORT TAXI CHART

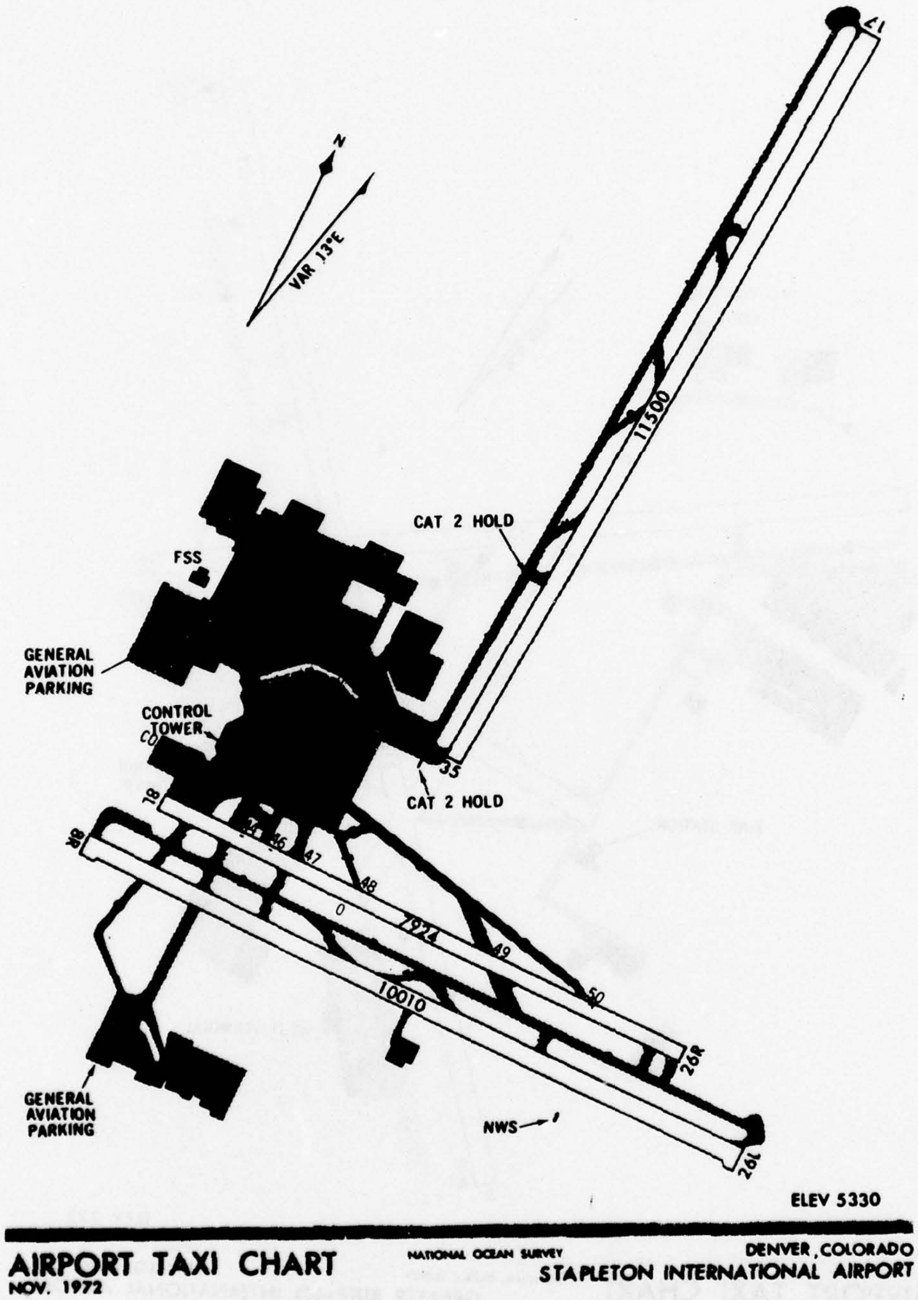

FIGURE A-3
DENVER AIRPORT TAXI CHART

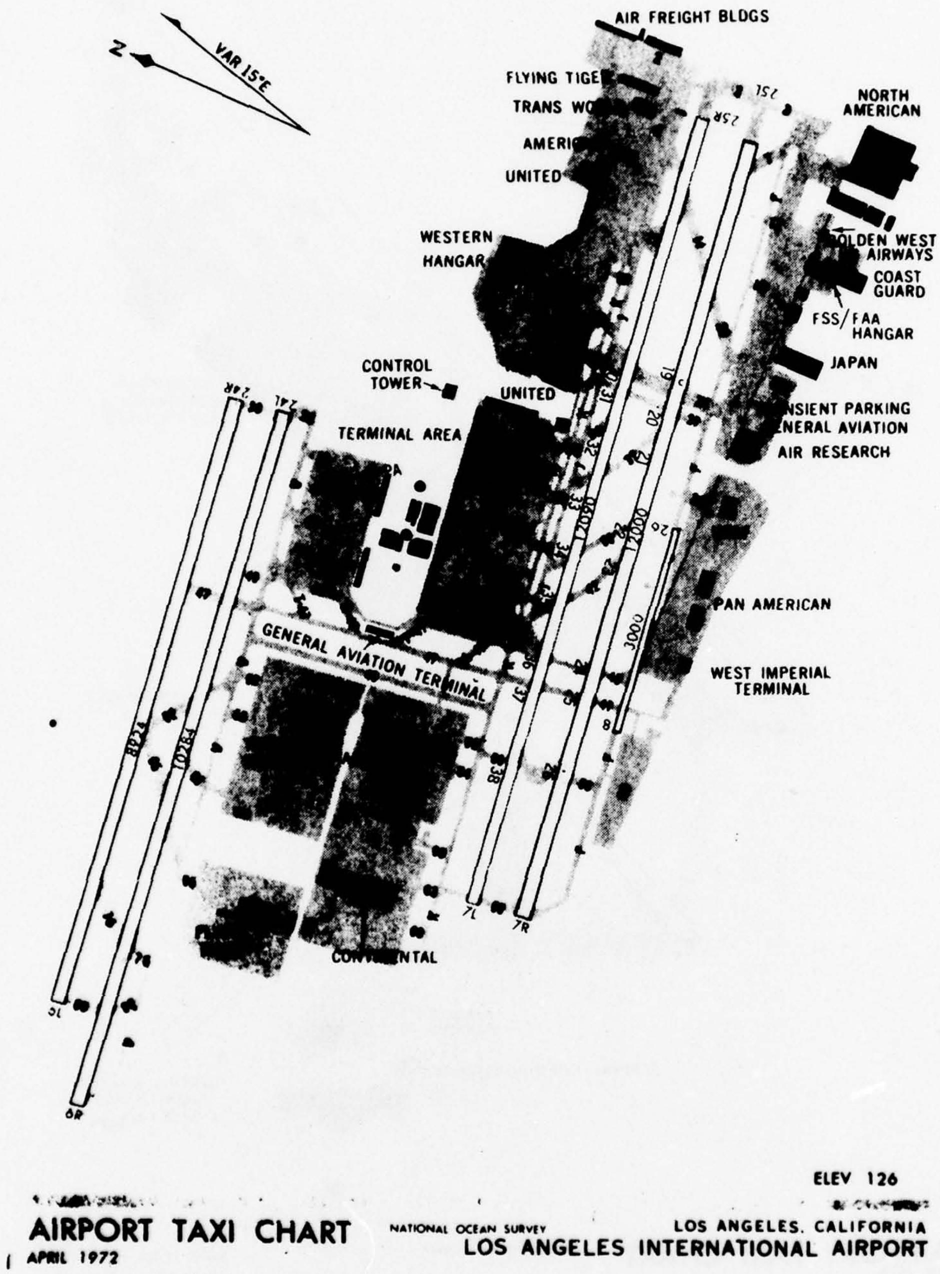

FIGURE A-4
LOS ANGELES AIRPORT TAXI CHART

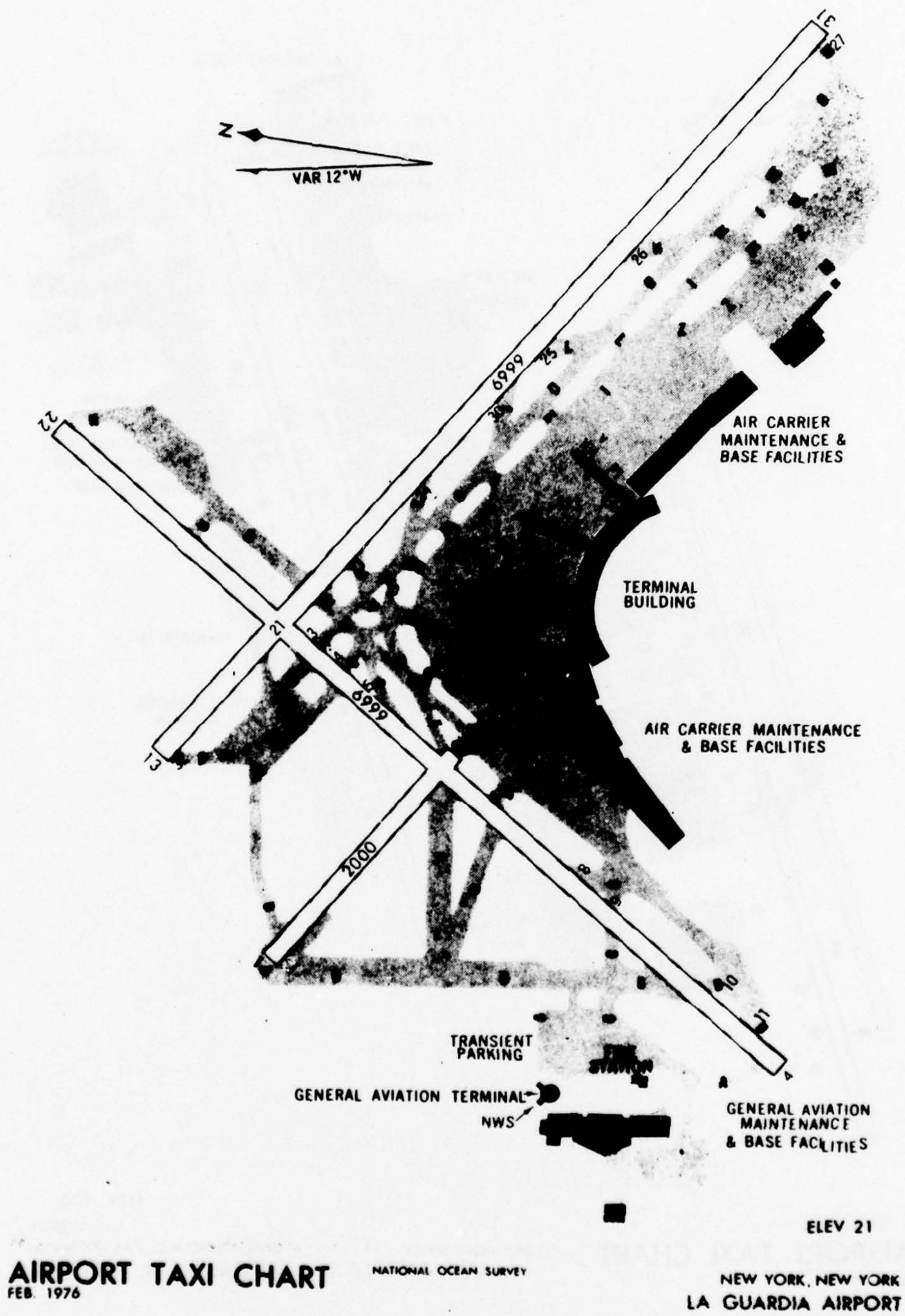

FIGURE A-5
LA GUARDIA AIRPORT TAXI CHART

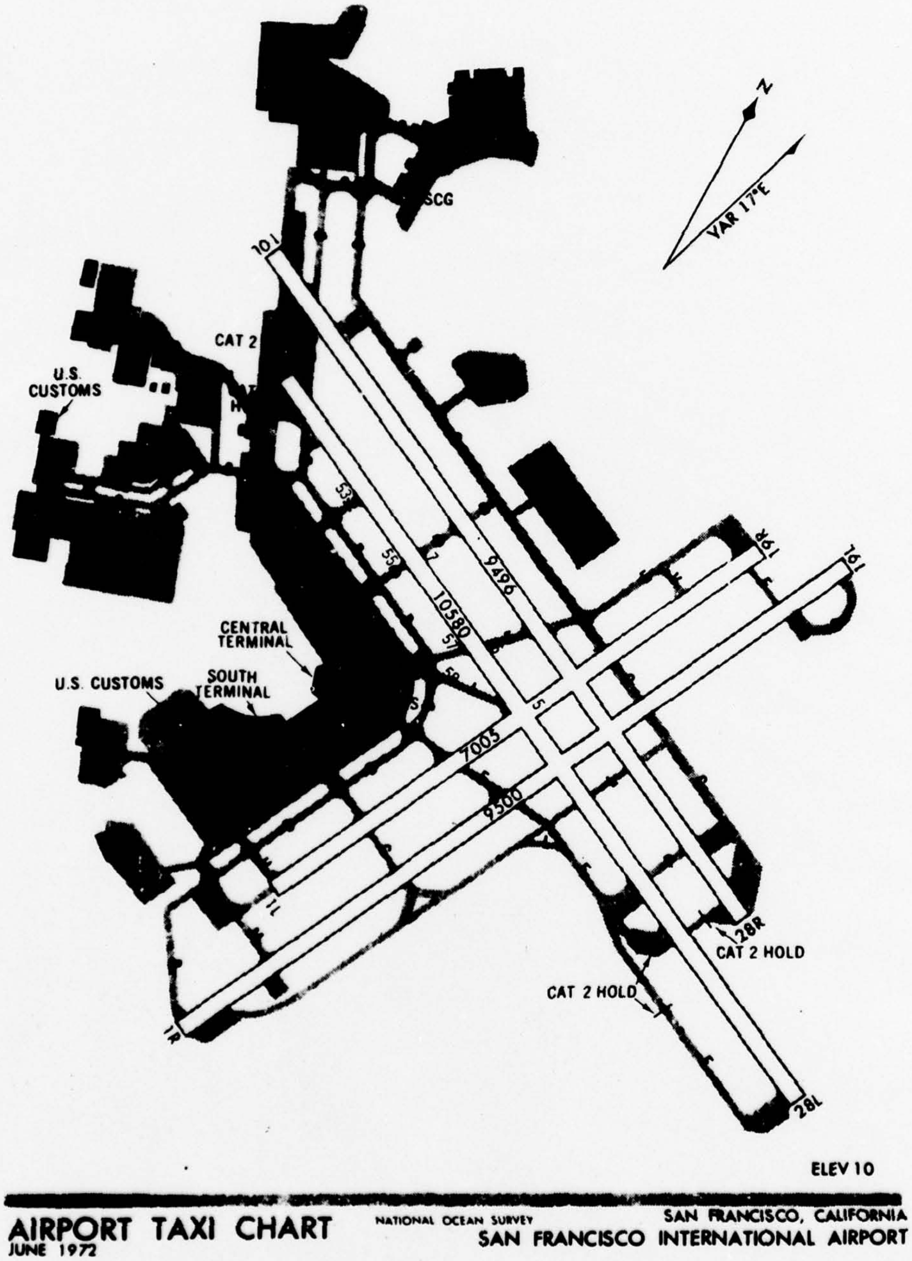

FIGURE A-6
SAN FRANCISCO AIRPORT TAXI CHART

APPENDIX B

RUNWAY DATA

Data found in this section is ranked by carrier from most to least motivated with respect to desire to exit early. The details of this classification system are found in Section 3.3. The small connecting lines which group individual carriers indicate similar levels of motivation. The connecting lines closest to the carrier name indicate secondary motivational levels and the ones to the right (if any) show primary levels of motivation.

TABLE B-1
ATLANTA 27R (26) RUNWAY DATA
GROUP 3

Runway: ATL 27R (26) Class: 3	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Carrier Name				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Delta	25	50.7	8.9			2		2	3	8	7	2			1			
2. United	16	47.6	4.3					1	7	7		1						
3. Southern	3	52.0	7.0						1	1		1						
4. Piedmont	7	50.6	5.8						2	2	2	1						
5. Eastern	46	53.2	7.4					1	10	15	8	9	1		2			

Carrier Name	Total Observations	Distribution of Observations by Exit										
		10	9	8	7	6	5	4	3	2	1	24
1. Delta	25	1	1		1	1	9	1	11			
2. United	16				1	2	6	4	2		1	
3. Southern	3								2	1		
4. Piedmont	7								6	1		
5. Eastern	46						1	1	36	6	2	
Total Observations	97	1	1	-	2	3	16	6	57	8	3	-
Average ROT	51.4	32.0	32.0	-	50.0	48.3	49.8	44.8	52.3	56.6	59.0	-
Standard Deviation	7.5	0.0	0.0	-	14.1	3.8	7.9	3.9	5.2	9.8	13.9	-
Exit Distance	-	2480	4215	4959	5124	5537	5868	6116	6694	7190	7603	9669

TABLE B-2
BUFFALO 5 RUNWAY DATA
GROUP 3

Runway: BUF 5	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
Class: 3				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Carrier Name				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Allegheny	16	47.4	8.6					5	5	3	1		1	1				
2. Eastern	3	45.3	1.2						3									
3. United	7	46.7	13.9			1	1		2	1	1				1			
4. American	7	64.3	19.0					1		1	1	1		1		1		1

Carrier Name	Total Observations	Distribution of Observations by Exit					
		8	7	6	4	3	1
1. Allegheny	16	1		1	12	2	
2. Eastern	3				2	1	
3. United	7		1	1	4	1	
4. American	7				1	3	3
Total Observations	33	1	1	2	19	7	3
Average ROT	50.7	64.0	30.0	58.5	44.8	44.9	82.0
Standard Deviation	13.8	0.0	0.0	14.9	7.8	18.0	13.5
Exit Distance	-	1897	2922	3332	4665	5639	7997

TABLE B-3
BUFFALO 23 RUNWAY DATA
GROUP 3

Runway: BUF 23 / Class: 3 / Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds) 20 (0-22)	25 (23-27)	30 (28-32)	35 (33-37)	40 (38-42)	45 (43-47)	50 (48-52)	55 (53-57)	60 (58-62)	65 (63-67)	70 (68-72)	75 (73-77)	80 (78-82)	85 (83-87)	90 (88-99)
1. American	25	52.4	10.2					1	6	9	4	3		1				1
2. United	16	52.1	11.3				1		7	2	2	1	1	1		1		
3. Eastern	14	59.0	4.5								4	7	2	1				
4. Allegheny	69	57.4	7.5						3	14	25	12	10	2	2	1		

Carrier Name	Total Observations	Distribution of Observations by Exit 6	7	8	10
1. American	25	8	9	6	2
2. United	16	11	3	2	
3. Eastern	14		1	13	
4. Allegheny	69			68	1
Total Observations	124	19	13	89	3
Average ROT	55.9	46.8	53.8	57.3	77.3
Standard Deviation	8.7	8.8	6.6	6.7	9.2
Exit Distance	-	4768	5178	6203	7997

TABLE B-4
DENVER 26R RUNWAY DATA
GROUP 3

Runway: DEN 26R Class: 3 Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds) 20 0-22	25 23-27	30 28-32	35 33-37	40 38-42	45 43-47	50 48-52	55 53-57	60 58-62	65 63-67	70 68-72	75 73-77	80 78-82	85 83-87	90 88-99
1. Trans World	18	50.3	6.6					2	4	6	3	2	1					
2. Frontier	40	58.3	11.5	1				1	3	3	10	6	9	3	4			
3. Ozark	5	51.0	3.2						1	3	1							
4. North Central	3	58.3	5.5								1	1	1					
5. Texas Int'l.	8	47.9	4.3					1	4	1	2							
6. Western	35	46.1	6.2				2	8	10	10	3	2						
7. Continental	58	47.8	8.0			1		6	16	22	12	1						
8. United	127	51.6	7.8				3	11	21	41	26	14	7	2	1	1		
9. Braniff	20	56.9	7.1				1			3	7	5	3	1				

Carrier Name	Total Observations	Distribution of Observations by Exit 49	48	47	46	44										
1. Trans World	18			9	6	3										
2. Frontier	40		1	2	21	16										
3. Ozark	5			5												
4. North Central	3				3											
5. Texas Int'l.	8			8												
6. Western	35	1	4	23	7											
7. Continental	58		3	37	18											
8. United	127		6	77	44											
9. Braniff	20			1	16	3										
Total Observations	314	1	14	162	115	22										
Average ROT	51.5	38.0	38.8	48.4	56.0	60.9										
Standard Deviation	8.4	0.0	5.9	4.7	7.3	12.9										
Exit Distance	-	3130	5087	5967	6457	6946										

TABLE B-5
LOS ANGELES 25L RUNWAY DATA
GROUP 3

Runway: LAX 25L / Class: 3	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Carrier Name				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. United	18	44.8	8.0			1	2	5	3	5	2							
2. Hughes	8	50.3	5.5					1	1	4	2							
3. Continental	11	46.5	17.9			1	2	3	3				1					1
4. Pac. Southwest	11	39.5	9.7			2	4	2	1	1		1						
5. Mexicana	6	53.5	12.2						3		1	1			1			
6. Western	12	50.3	4.8					1	2	5	3	1						
7. American	12	50.4	8.9				2		1	3	5		1					
8. Trans World	16	51.9	9.3					1	8	2		2	2	1				
9. National	4	51.0	7.4						2		1	1						

Carrier Name	Total Observations	Distribution of Observations by Exit				
		21	22	23	24	26
1. United	18	8	10			
2. Hughes	8	1	6	1		
3. Continental	11	2	8			1
4. Pac. Southwest	11	7	3	1		
5. Mexicana	6		1	5		
6. Western	12	2	8	2		
7. American	12	1	3	8		
8. Trans World	16	1		14	1	
9. National	4	1	1	2		
Total Observations	98	23	40	33	1	1
Average ROT	48.2	37.9	49.2	52.0	71.0	93.0
Standard Deviation	10.4	5.8	7.0	8.4	0.0	0.0
Exit Distance	-	4607	6000	6536	8250	9750

TABLE B-6
LOS ANGELES 25R RUNWAY DATA
GROUP 3

Runway: LAX 25R Class: 3 Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. United	26	52.6	13.7				3	5	1	5	4	4	1	1	1			1
2. Hughes	9	50.8	20.4	2			1				2	1	1	1	1			
3. Continental	5	44.4	6.3				1	1	1	2								
4. Pac. Southwest	55	50.0	11.9		3		2	11	8	6	9	9	3	3		1		
5. Mexicana	4	41.3	18.3	1					1	1	1							
6. Western	30	56.0	13.0			2	1	2	2	4	5	3	5	4	1	1		
7. American	5	75.2	12.8										1	2		1		1
8. Trans World	4	61.5	7.5								1	1	1	1				

Carrier Name	Total Observations	Distribution of Observations by Exit				
		31	32	33	34	35
1. United	26		4	15	7	
2. Hughes	9	1	2	5	1	
3. Continental	5			4	1	
4. Pac. Southwest	55		4	39	12	
5. Mexicana	4		1	1	2	
6. Western	30	1	5	12	7	5
7. American	5		2		3	
8. Trans World	4	1			1	2
Total Observations	138	3	18	76	34	7
Average ROT	52.6	68.7	54.3	49.4	54.3	60.7
Standard Deviation	14.1	8.1	20.9	12.5	14.0	14.4
Exit Distance	-	4136	4666	5515	6787	7424

TABLE B-7
LA GUARDIA 22 RUNWAY DATA
GROUP 3

Runway: LGA 22 / Class: 3	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Carrier Name				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Piedmont	5	34.6	8.1		1	1	1	1	1									
2. Eastern	80	42.6	9.7		1	9	13	23	13	9	6	1	3	2				
3. Trans World	38	41.4	7.3		1	3	9	8	11	4	1	1						
4. North Central	3	47.0	13.9			1					2							
5. Delta	16	47.5	7.5				1	4	3	2	6							
6. Allegheny	17	42.2	9.1			2	5	2	4	1	2		1					
7. United	42	43.1	10.1	1	2	2	6	10	9	6	3	1	1		1			
8. Ozark	3	44.0	11.1				1	1			1							
9. National	8	47.9	6.3					3	1	2	2							
10. American	103	43.7	10.9	1	2	7	17	25	18	12	9	7	2	2	1			

Carrier Name	Total Observations	Distribution of Observations by Exit					
		6	7	8	9	10	11
1. Piedmont	5			5			
2. Eastern	80		8	46	4	21	1
3. Trans World	38	1		29		8	
4. North Central	3			3			
5. Delta	16		2	5	1	8	
6. Allegheny	17		1	10	1	5	
7. United	42	1	7	25	2	7	
8. Ozark	3			3			
9. National	8			2	2	4	
10. American	103	1	5	58	10	29	
Total Observations	315	3	23	186	20	82	1
Average ROT	43.3	47.0	40.1	40.4	50.9	48.9	54.0
Standard Deviation	9.5	4.6	9.5	8.8	11.2	8.7	0.0
Exit Distance	-	3678	4189	4955	5160	6233	6692

TABLE B-8
LA GUARDIA 31 RUNWAY DATA
GROUP 3

Runway: LGA 31 / Class: 3	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Carrier Name				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Piedmont	3	38.0	7.9			1		1	1									
2. Eastern	22	38.9	9.5		2	2	6	7	2	1	1		1					
3. Trans World	14	39.9	6.8			2	3	3	4	2								
4. Delta	5	43.6	5.0					3		2								
5. Allegheny	7	41.4	6.3			1	1	2	1	2								
6. United	14	41.4	8.7			3	2	1	6	1		1						
7. National	4	48.0	15.9				1	1	1					1				
8. American	34	40.8	8.3			3	12	8	5	4		1		1				

Carrier Name	Total Observations	Distribution of Observations by Exit				
		24	23	22	21	32
1. Piedmont	3	1	2			
2. Eastern	22	10	11			1
3. Trans World	14	4	8	1	1	
4. Delta	5	3	2			
5. Allegheny	7	6	1			
6. United	14	5	8	1		
7. National	4		3			1
8. American	34	10	18	4		2
Total Observations	103	39	53	6	1	4
Average ROT	40.7	36.4	42.2	39.2	46.0	63.5
Standard Deviation	8.5	6.4	6.7	4.5	0.0	11.9
Exit Distance	-	4291	5058	5415	5773	6948

TABLE B-9
SAN FRANCISCO 28R RUNWAY DATA
GROUP 3

Runway: SFO 28R / Class: 3 / Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Western	25	45.9	8.4			1	3	6	6	3	5		1					
2. Trans World	7	49.3	10.9				1		3	1	1			1				
3. American	5	48.0	11.3				1		2	1			1					
4. Pac. Southwest	15	42.5	6.2			1	2	4	6	1	1							
5. National	3	54.0	5.3							1	1	1						
6. Hughes	7	48.1	7.2				1		1	3	2							
7. United	31	49.7	10.4				2	3	14	4	3	2	1		1		1	

Carrier Name	Total Observations	Distribution of Observations by Exit			
		5	6	7	8
1. Western	25	2	7	15	1
2. Trans World	7			6	1
3. American	5		1	3	1
4. Pac. Southwest	15		8	7	
5. National	3			3	
6. Hughes	7		1	6	
7. United	31		2	27	2
Total Observations	93	2	19	67	5
Average ROT	47.4	56.5	40.4	47.3	72.0
Standard Deviation	9.2	7.1	5.1	6.7	7.4
Exit Distance	-	3415	4165	5664	8496

TABLE B-10
SAN FRANCISCO 28L RUNWAY DAY
GROUP 3

Runway: SFO 28L Class: 3 Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Western	21	49.7	8.4					3	8	4	3	2			1			
2. Continental	3	63.0	18.0							1		1					1	
3. Trans World	4	48.3	6.8					1	2			1						
4. Pac. Southwest	44	48.1	7.1				2	6	16	11	6	1	1		1			
5. Hughes	14	48.6	7.7				1	3	2	4	1	3						
6. United	52	49.7	7.9					7	16	16	7	1	3	1	1			

Carrier Name	Total Observations	Distribution of Observations by Exit			
		58	57	55	53
1. Western	21	20	1		
2. Continental	3	1	1	1	
3. Trans World	4	4			
4. Pac. Southwest	44	42	1		1
5. Hughes	14	14			
6. United	52	49	2	1	
Total Observations	138	130	5	2	1
Average ROT	49.3	48.3	58.4	80.0	75.0
Standard Deviation	8.1	6.7	5.7	4.2	0.0
Exit Distance	-	5802	6570	7850	8788

TABLE B-11
DENVER 26R RUNWAY DATA
GROUP 4

Runway: DEN 26R Class: 4 Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds) 20 0-22	25 23-27	30 28-32	35 33-37	40 38-42	45 43-47	50 48-52	55 53-57	60 58-62	65 63-67	70 68-72	75 73-77	80 78-82	85 83-87	90 88-99
1. Trans World	9	52.0	8.1				1		1	2	4		1					
2. Continental	21	53.7	8.5					1	5	6	3	3	2			1		
3. Western	16	59.1	13.3				1		1	3	1	6	2		1			1
4. United	54	54.9	8.3					3	7	10	15	10	6	1	1	1		

Carrier Name	Total Observations	Distribution of Observations by Exit 47	46	44
1. Trans World	9	2	6	1
2. Continental	21	13	8	
3. Western	16	5	10	1
4. United	54	24	26	4
Total Observations	100	44	50	6
Average ROT	55.1	49.0	60.2	60.7
Standard Deviation	9.4	6.0	8.3	7.9
Exit Distance	-	5967	6457	6946

TABLE B-12
LOS ANGELES 25L RUNWAY DATA
GROUP 4

Runway: LAX 25L / Class: 4	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Carrier Name				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. United	40	50.9	11.0			1	1	2	10	14	6	3	1		1			1
2. Continental	15	47.4	7.5				1	4	3	2	5							
3. Delta	7	47.1	10.0					2	4					1				
4. Western	20	49.5	6.4					1	6	10		2	1					
5. American	27	50.6	10.2				1	4	5	10	1	2	1	1	2			
6. Trans World	33	53.3	9.7					4	4	12	4	3	4		1	1		
7. National	4	57.3	11.2						1		2			1				
8. Pan Am	4	53.3	8.5						1	1	1		1					

Carrier Name	Total Observations	Distribution of Observations by Exit				
		21	22	23	24	25
1. United	40	3	23	12	1	1
2. Continental	15	4	10	1		
3. Delta	7		4	2	1	
4. Western	20	1	10	9		
5. American	27		3	22	2	
6. Trans World	33		2	25	5	1
7. National	4			3		1
8. Pan Am	4			4		
Total Observations	150	8	52	78	9	3
Average ROT	50.9	41.6	48.8	50.1	67.0	83.7
Standard Deviation	9.6	6.2	6.6	7.1	8.7	13.9
Exit Distance	-	4607	6000	6536	8250	8679

TABLE B-13
LOS ANGELES 25R RUNWAY DATA
GROUP 4

Runway: LAX 25R Class: 4 Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. United	17	56.8	15.6					5	1	2	1	4	1	1	1			1
2. Continental	5	59.0	22.6						2	1	1							1
3. Western	11	59.4	19.4				1	1		2				2	3	1	1	
4. American	6	65.3	11.7							1		1	2		1	1		
5. Trans World	11	64.0	17.4				1	1		2				2	3	1	1	

Carrier Name	Total Observations	Distribution of Observations by Exit					
		31	32	33	34	35	36
1. United	17		3	5	8	1	
2. Continental	5			3	2		
3. Western	11	1	4	5	1		
4. American	6	1	1	1	1	1	1
5. Trans World	11	3	2		1	2	3
Total Observations	50	5	10	14	13	4	4
Average ROT	60.2	73.2	61.7	56.6	56.0	68.8	57.8
Standard Deviation	16.8	5.1	19.6	16.4	17.8	4.9	21.4
Exit Distance	-	4136	4666	5515	6787	7424	8166

TABLE B-14
SAN FRANCISCO 28R RUNWAY DATA
GROUP 4

Runway: SFO 28R	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
Class: 4				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Carrier Name				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Western	5	51.0	6.4						2	1	1	1						
2. Trans World	15	48.9	13.8	1				2	5	3	1	1		1		1		
3. American	10	62.3	17.1					2		2	1		1	1		2	1	
4. National	3	53.3	10.1						1	1			1					
5. Delta	3	81.3	5.5												1		2	
6. United	25	59.6	17.4					2	8	2	4		1		2	1	4	1

Carrier Name	Total Observations	Distribution of Observations by Exit		
		6	7	8
1. Western	5		5	
2. Trans World	15	1	12	2
3. American	10		5	5
4. National	3		2	1
5. Delta	3			3
6. United	25	3	13	9
Total Observations	61	4	37	20
Average ROT	57.5	39.0	48.0	78.7
Standard Deviation	16.5	15.2	5.2	7.4
Exit Distance	-	4165	5664	8496

TABLE B-15
SAN FRANCISCO 28L RUNWAY DATA
GROUP 4

Runway: SFO 28L Class: 4 Carrier Name	Total Observations	Average ROT	Standard Deviations	Distribution of ROT's by Time (Seconds)														
				20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
				0-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62	63-67	68-72	73-77	78-82	83-87	88-99
1. Pan Am	9	57.7	12.8					1	1	1	3		1		1	1		
2. Western	19	48.8	11.5		1		1	2	6	5	1	1	1			1		
3. Trans World	24	49.3	10.8		1		3	1	2	10	4	1	1			1		
4. American	28	52.2	10.4			1	1	2	7	2	9	2	2		2			
5. National	3	62.0	9.6								1	1			1			
6. Delta	10	69.3	12.3							1	1	1	2	1	1	2		1
7. United	37	59.0	14.6					1	6	10	6		6	2	1	1	1	3

Carrier Name	Total Observations	Distribution of Observations by Exit			
		58	57	55	53
1. Pan Am	9	7			2
2. Western	19	15	4		
3. Trans World	24	21	2	1	
4. American	28	19	3	3	3
5. National	3	1		1	1
6. Delta	10	1	1	7	1
7. United	37	23	6	5	3
Total Observations	130	87	16	17	10
Average ROT	55.0	48.4	61.3	72.8	74.0
Standard Deviation	13.4	6.9	14.5	9.9	12.0
Exit Distance	-	5802	6570	7850	8788

APPENDIX C

SELECTED FEDERAL AVIATION REGULATION LANDING DISTANCES[4]

Aircraft Type	FAA Landing Field Length (Feet)*
B-707-320 B and C	6250
B-727-100	4800
B-727-200	4150
B-737-200	4100
B-747-100	6200
DC-8-30	6800
DC-8-61	6000
DC-9-10	4470
DC-9-30	3900
DC-10-10	5140
L-1011-100	5800

*Conditions were not stated but assumed to be zero wind and runway gradient, standard day, hard dry runway surface, and maximum gross landing weight.

APPENDIX D

REFERENCES AND SOURCES

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